

Direct Imaging of Interfacial Spins in Exchange Coupled Co/NiO

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BACKGROUND

The determination of the crystallographic, electronic or magnetic structure of interfaces has remained one of the great challenges in all of materials science. The key reason is the difficulty to detect and isolate the weak interface signature from that of the dominant bulk. This is largely due to the lack of depth specificity of most techniques, impeding the detection of a signal from a well-defined depth, only. For lack of better capabilities scientists have tried to circumvent this problem, often studying the early stages of interface formation with surface science techniques or simply assuming "perfect" interfaces between "bulk" materials.

The exchange bias effect, empirically discovered nearly 50 years ago, is used today to create a well-defined ferromagnetic reference layer in a magnetic device. A natural ferromagnet has a preferred magnetization "easy axis", and an external field can align the spins into either of two equally stable directions along this axis - the magnetization loop is symmetric. If an AFM-FM system is grown in a magnetic field or, after growth, is annealed in a magnetic field to temperatures above the AFM Néel temperature, then the FM exhibits a preferred magnetization direction parallel to the applied field. Furthermore its coercivity is usually increased (even without external field applied). The easy alignment direction can serve as a reference direction in a device. It is clear that exchange bias has to originate from the coupling of the spins in the AFM to those in the FM but, because of the magnetic neutrality of the AFM, the coupling has to involve *uncompensated spins* at the AFM-FM interface. The key to the exchange bias puzzle lies in the determination of the origin of these interfacial spins and their role in the magnetic properties of the system. It is the very difficulty associated with the determination of

the magnetic interfacial structure mentioned above, that has impeded the solution of the exchange bias puzzle for more than forty years. X-ray magnetic circular (XMCD) and linear (XMLD) dichroism techniques in conjunction with spectro-microscopy these x-ray techniques now allow a unique fresh look at the old exchange bias problem and hold the promise to finally solving it.

RESULTS

Results were obtained by two complementary experiments, high energy resolution (150 meV) soft x-ray absorption spectroscopy in total electron yield mode performed at Beam Line 10-1 at SSRL and high spatial resolution (50 nm) soft x-ray absorption microscopy using the PEEM2 microscope at the ALS. Figure 1 shows how the spectroscopic knowledge was used to isolate the signal arising from the interfacial spins. The NiO XMLD image at the bottom and the Co XMCD image at the top demonstrate the parallel coupling between antiferromagnet and ferromagnet as it was reported earlier [1]. In addition spectra of pure ferromagnetic Co or Ni metal and pure antiferromagnetic CoO and NiO monoxides are shown. X-ray absorption spectra of thin Co layers (up to 10 monolayer) deposited on NiO deviate significantly from the pure metal and furthermore the deposition leads to a change in the NiO absorption spectra. The changes are interpreted in terms of a chemical process that leads to reduction of NiO to Ni and oxidation of Co to CoO and thus to the formation of a thin CoNiO_x like interfacial layer. Absorption spectra obtained from such systems can be fitted by linear combination of these two single components. The absorption resonances of nickel oxide and metal are slightly different (0.3eV) and by tuning the photon energy appropriately the contribution of metal like Ni sites is enhanced and using circular polarization their ferromagnetic domain pattern can be imaged. This is shown in the middle image of figure 1. A close look on the domain pattern reveals that the domains mimic the antiferromagnetic NiO domains below and the ferromagnetic Co domains above and therefore form the bridge between the two. The absolute number of interfacial spins determined by the size of the ferromagnetic contrast increases with annealing of the sample corroborating the fact that its origin is indeed a chemical reaction. We point out that none of the samples investigated have shown any detectable exchange bias. It is known that exchange bias on single crystals is rather small and scales with the inverse domain size. In contrast the coercivity of the films roughly followed the number of uncompensated spins and could be increased up to 0.15T.

The results show that interfacial spins at the Co/NiO interface are created by a chemical reaction. They are shown to be responsible for the coercivity increase usually observed in AFM-FM exchange coupled systems.

References

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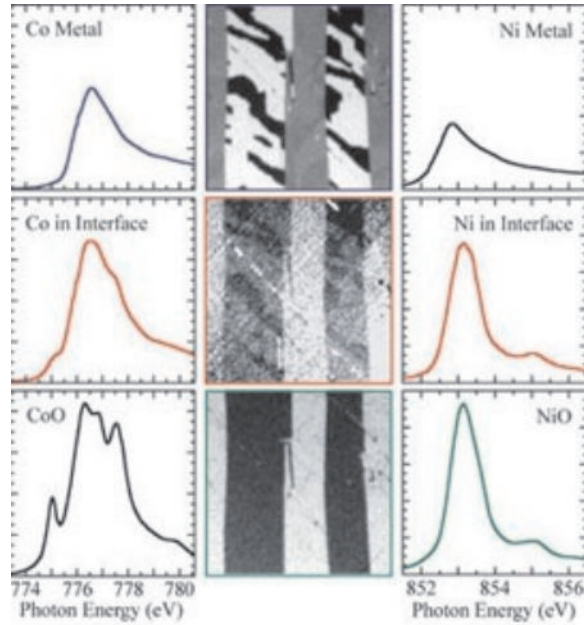


Figure 1: Co (left column) and Ni (right column) high resolution L_3 edge x-ray absorption spectra resolving the fine structure of the metal (top) and the oxide (bottom). The XAS of the Co and Ni atoms in the interfacial layer (middle) reveal a chemical reaction of Co oxidation and Ni reduction. The resulting spectra can be understood as a linear combination of metal and oxide spectra. By choosing appropriate photon energies and polarization x-ray photoemission electron microscopy images (XPEEM) reveal the ferromagnetic domain pattern of Co the antiferromagnetic domain pattern of NiO and the interfacial spin polarization of the interfacial spins (middle).

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